User Manual for CREANUIS

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Introduction

1.1 General overview

CREANUIS is a tool that simulates nonlinear radio frequency (RF) ultrasound images. It is the combination of two specific tools. The former is a nonlinear ultrasound propagation simulator, that allows to compute the evolution of the fundamental and second-harmonic wave [1]. Then, using this field information, a reconstruction algorithm creates the corresponding nonlinear radio frequency (RF) image [2]. The resulting RF image contains the fundamental evolution, but also the second harmonic one. The design of the nonlinear propagation simulator, which is a generalization of an angular spectrum method (GASM), allows to consider media with an inhomogeneous coefficient of nonlinearity and the simulated field will impact the final RF image simulation. Efforts on the computation time have been made on the nonlinear field with a version of the software working on GPU (graphic processing unit) [3].

1.2 Software description

CREANUIS has been designed in C/C++ in order to perform a quick simulation of the nonlinear propagation and of the RF images. An interface is proposed in Qt[1], but can also be disabled. In the GASM simulations, the Fourier transform are performed using the FFTW library[2] [4], or the cuFFT library[3], when the GPU programming is used. Some accompanying files are proposed to load the simulated data with Matlab. The structures of the saved data are detailed hereafter and the image can also be loaded with another program as soon as an interpreter is designed.

2 Installation

2.1 Windows

On windows, the provide package install the various required exe and dll files. The vcredist_x86, if not present on the system, has also to be installed. During the installation of CREANUIS, the path of the installation has to be change (**do not used Program Files/ directory**) because last windows operating system forbids to write in this directory. Additional Matlab files are given in the installation direction. Three folder are also generater where the CREANUIS programm is install and are required to correctly executing the software (input/, nlrf_file/, pressure_field/).

2.2 Linux (Fedora) distribution

On Fedora distribution, the tar.gz file has just to be extracted. Then, the program can directly be used. The same directories as in the Windows installation are created and required.

[1] http://qt.nokia.com/products/
[2] http://www.fftw.org/
[3] http://developer.nvidia.com/cuda-downloads

2.3 Created folder

Three directories are created by the install files and are required in the same root direction. The input folder is used to save some user inputs. All the created **nonlinear radio frequency (nlrf)** images are saved in the nlrf_file folder. The field, the nonlinear coefficient map and the settings (if saved) are saved in the pressure_field folder.

3 Interface description

The CREANUIS interface is divided in three distinct thumbs coupled to some general settings.

3.1 General settings

In the general settings (Fig. 1) the user can defined the path of the working directory of CREANUIS (G2). By default, this path is set to the directory where the CREANUIS exe file is located, with the addition of the directory pressure_field/a_default. This path can be changed using the button G3. In the box G4, the name of the output file can be chosen. If the file exists in the nlrf_file directory, it replaces the previous nlrf file. The G5 button launches the simulation. The box G6 corresponds to the debug level wanted. If 0 is chosen, just some messages are displayed in the terminal. If 1 is selected, the debug messages corresponding to the RF image reconstruction are displayed. With 2, the messages of the GASM simulation are also displayed.

In the G1 menu, settings can be saved or loaded in the action menu. The help menu displays a link to the CREANUIS web site and the licence specification. The save/load actions save or load the data in the save_settings.txt file. This file is created/readed in the path directory G2.

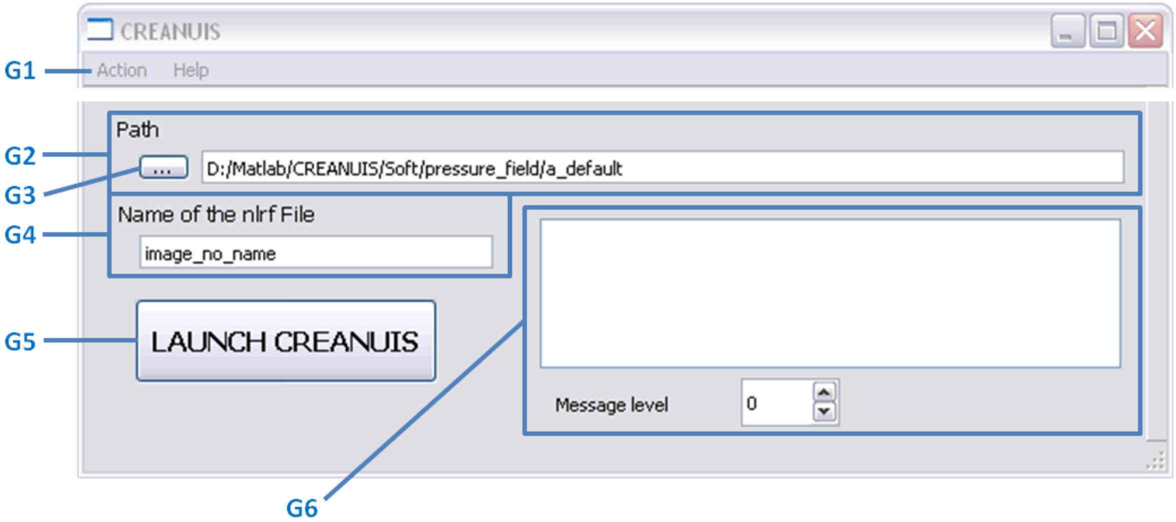

Fig. 1. Illustration of the general settings of the CREANUIS interface.

3.2 Probe, space and beamforming strategy

The first part of the interface (Fig. 2) allows to specify the probe geometry (P), the medium characteristics (M) and the beamforming configuration (B). All these parameters are saved in the save_setting.txt file. In the B menu, the user can save the pre-beamformed data. In that case, for each RF line, all the elementary received RF lines on each active element are saved. The user has to take care of the large size of the resulting nonlinear RF data that can be generated.

Currently, only linear arrays are simulated with CREANUIS. In a future version of CREANUIS, more complex arrays are going to be taken into account. For the attenuation, a frequency dependent law has been chosen because the second harmonic wave is faster attenuated than the fundamental one [5].

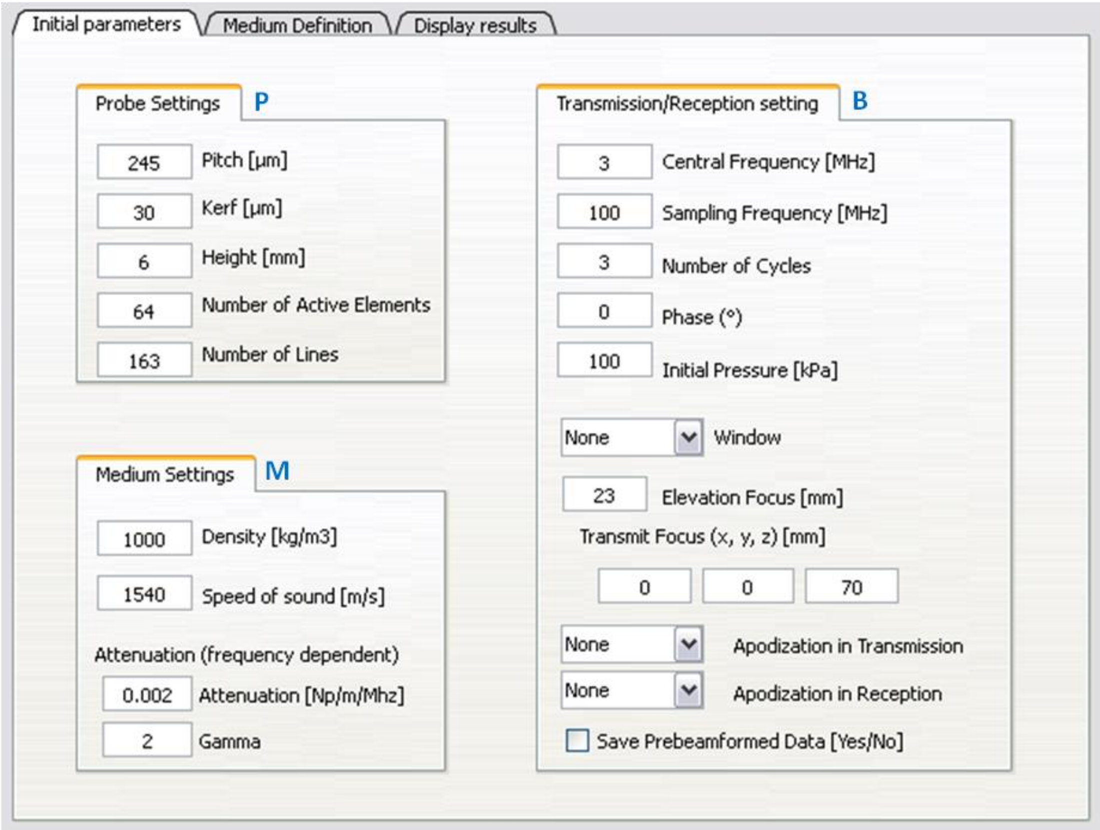

Fig. 2. Illustration of the probe, medium and beamforming settings in the CREANUIS interface.

3.3 Scatterers and GASM configuration

In this second thumbs (Fig. 3) the scatterers of the medium (S) and the nonlinear map (NL) are configured.

In the scatterers part (S), the dimensions of the space where the scatterers are placed are defined with the maximum lateral and elevation distances. In the *z* direction, the minimal and maximal depths to reach are defined. These depths are the one used in the final image creation. The scatterers' density, N, allows to quickly select the number of scatterers per resolution cell. However, in some cases, this number is directly the number of scatterers in the medium. For example with the diagonal, vertical or PSF configuration, exactly N scatterers are used in the medium. Moreover, with

the grid scatterers configuration, a grid of N x N is design to simulate the medium. The backscattering amplitude follows a normal distribution. The scatterers distribution can also be imported from a file.

Concerning the GASM configuration (NL), the discretisation in the *x*, *y*, and *t* axis is performed in the definition of the 3D matrix in the GASM simulation. The discretization of the z axis defines the different incremental step in the computation of the second harmonic field. Then, the obtained field is interpolated using the interpolation dimension on the *z* axis. In the right part, some pre-configured situations of nonlinear coefficient map are proposed. The default map is a constant medium with β=3.5. Then, by clicking on the add button, the user modifies the map using a new β value. The different checkable boxes have different actions:

- Compute one way field: if selected, only the GASM simulation is performed (no impact of scatterers and image creation). The field is saved with the same output name as the nlrf image, but in the current path.
- Compute GASM: if selected, the GASM simulations are conducted. Otherwise, the saved field in the current folder is loaded. This option is useful to save computation time when the field has already been simulated.
- Save all the fields: if selected, the fields computed are saved.
- Use GPU: if selected, the GASM simulations are conducted on the GPU if it is correctly initialized.

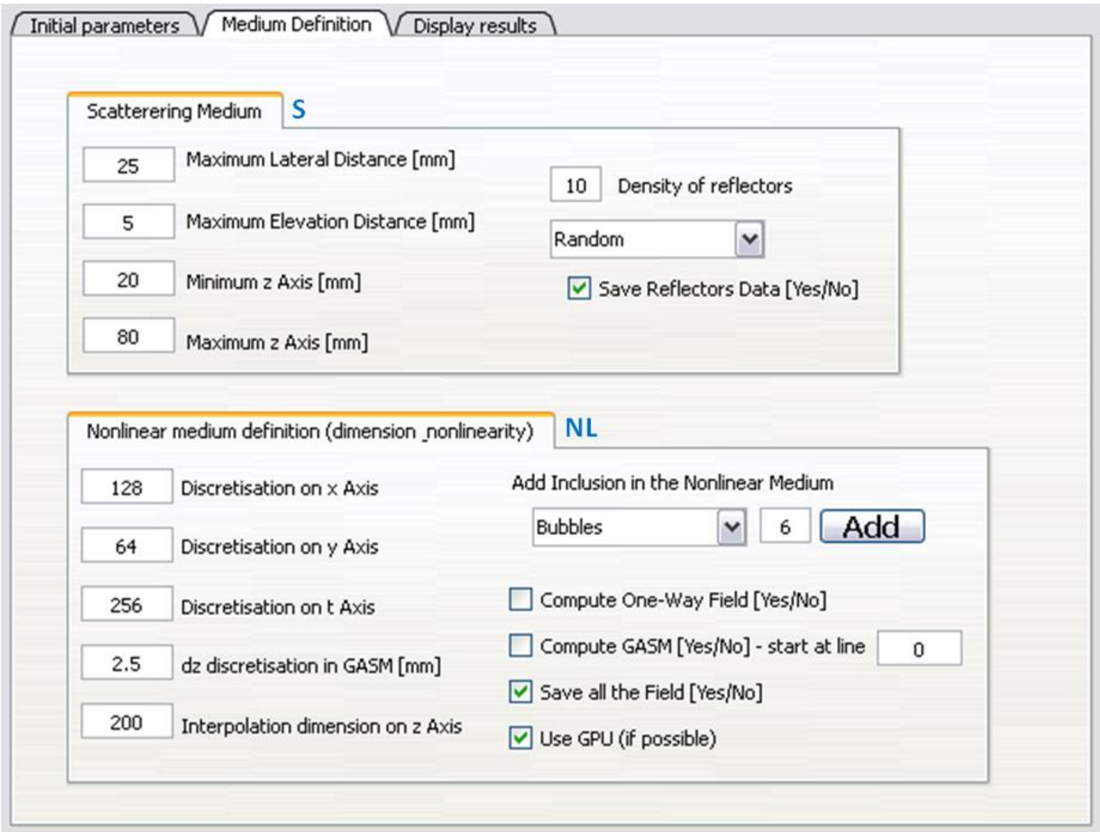

Fig. 3. Illustration of the scatterers definition and the GASM configuration.

Existing nonlinear coefficient map can be imported by the user. The dimension of the imported image has no impact because interpolation is used in the field simulations. However, it has to be considered that the dimension of the map is set by the probe and space parameter. Indeed, the

nonlinear map will have a dimension in the lateral dimension [-N_{line} Pitch ; N_{line} Pitch] and in the axial dimension [0; z_max]. The number of points, that composes this image, has no impact once loaded in CREANUIS.

3.4 Display results menu

This last thumb (Fig. 4) is the display interface. It allows to see the nonlinear coefficient, the pressure field or the nonlinear RF (nlrf) file. The different buttons allow to select some other file, and to quickly visualize the different results. D1 allows to display the current nonlinear coefficient map, D2 to load an existing pressure field and D3 to load an exiting nlrf image. For the last two, the fundamental and second-harmonic component is displayed in the left and right part of the thumb.

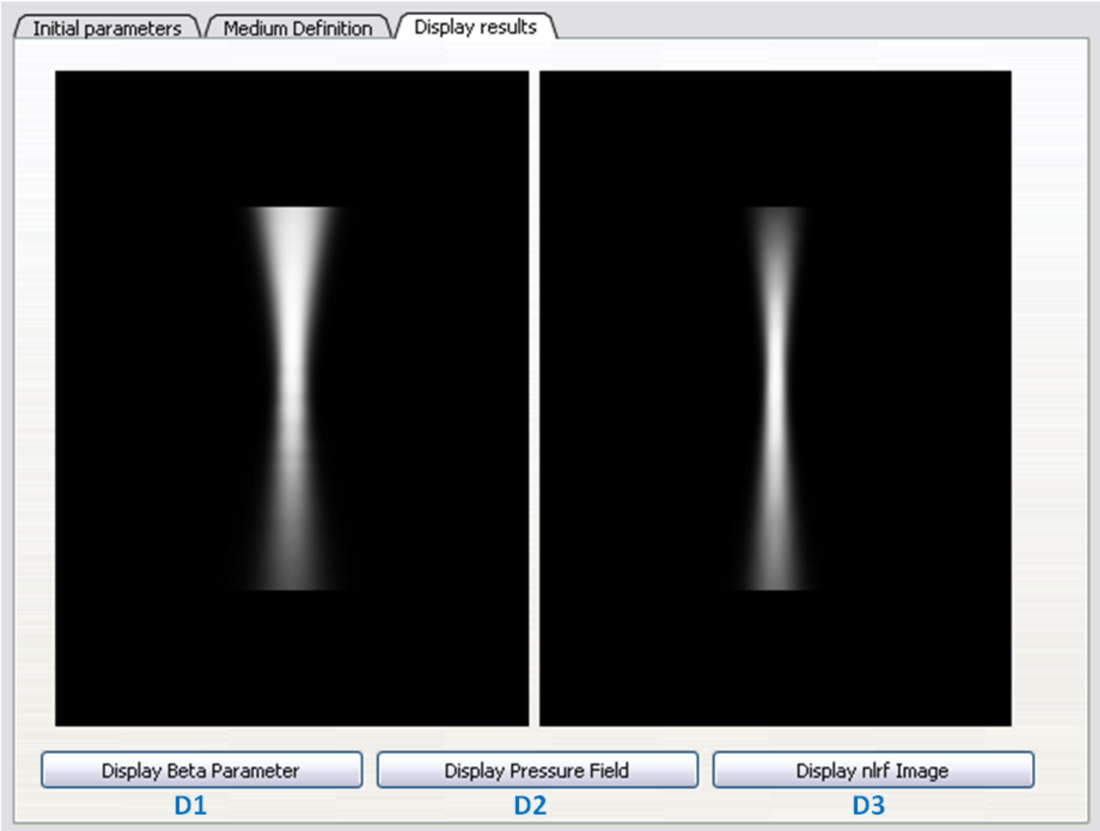

Fig. 4. Illustration of the display thumbs and the possibility to visualize the nonlinear coefficient, the pressure field and the nonlinear image.

4 Data structure

4.1 Nlrf files

The nlrf file is the output format of the nonlinear RF image that is computed by CREANUIS. The file is a binary file only writen with floats numbers. A header of 18 floats is present. The header different data are saved in the following order:

HEADER: Transmitted frequency, sampling frequency, speed of sound, initial pressure, density, pitch, kerf, height, number of elements, number of points on one RF line, third dimension of the RF image (different of 1 if the pre-beamformed data are saved), number of active elements, transmitted focus (z direction), elevation focus, minimal depth, maximal depth, number of transmitted cycles, transmitted phase (in degree).

Then, the other elements correspond to the amplitude of the RF image. The dimension of the radio frequency image is given by the number of probe element by the number of points on one RF line by the number of active element if pre-beamformed image is saved.

4.2 Nonlinear coefficient files

The nonlinear coefficient file is a binary file that contains first, two entire N and M, and then NxM float elements. To create a nonlinear coefficient file, such configuration has to be used in order to be understood by CREANUIS.

4.3 Scatterers files

The scatterers file is a binary file that contains first, an entire N and then the position and the amplitude of each scatterer (in float). The rest of the file is successively composed of the N positions *x*, the N positions *y*, the N positions *z* and the N amplitude values. To create a scatterer file, such configuration has to be used in order to be understood by CREANUIS.

5 Utilization of CREANUIS in command line

CREANUIS can be used in command line in order to suppress the graphic interface and then, launch the simulation in a cluster for example. To do this, some arguments have to be added after the CREANUIS is launched.

Obligatory arguments

- --path path_name: the user must specify the path where the save_settings.txt file is backup in order to access to the entire parameters need to configure CREANUIS. If the setting file is not placed in path_name directory, an error is return by CREANUIS.
- --scatterers scatterers_file: the user must specify the file where the scatterers position and amplitude are saved. Using CREANUIS in command line did not yet allow to used the classical random, diagonal, grid,... distribution. This file can be generated using the accompanying Matlab file.

Optional arguments

- --nonlinearity nonlinear_coefficient_file: if a specific nonlinear coefficient medium is desired, it has to be generated previously. If the –nonlinearity tag is not present, a nonlinear coefficient medium of β=3.5 is used in the GASM simulations.
- --debug debug_number: if the output messages are desired in the terminal, a number above 0 has to be selected. The number are the same as the graphic use of CREANUIS. Let recall

that the tag do_gasm in the save_setting.txt has to be equal to 1 to do the GASM simulations.

6 Accompanying Matlab files

With CREANUIS, several accompanying files are proposed to be able to use the produced results in a Matlab interface. The files are divided in two categories and are summarized in Table 1:

- Files to read information saved by CREANUIS
- Files to write information that can be read by CREANUIS

Table 1. List of the accompanying Matlab files.

Read	Write
read_nonlinear_coefficient_file.m	write_nonlinear_coefficient_file.m
read_scatterers_file.m	write_scatterers_file.m
read_image_rf.m	write_image_rf.m
read_field.m	write_apodization.m

The action of each file is detailed in the help header of the Matlab file. If specific apodization, scatterers or nonlinear medium are required, it is recommended to use these files.

7 Licence

The CREANUIS software has been placed under the CeCILL-B licence[4]. This licence gives to the user the authorization to use CREANUIS and to publish works obtained using this software. The only condition is to cite in each work where CREANUIS has been used the following publications:

- F. Varray, A. Ramalli, C. Cachard, P. Tortoli, and O. Basset, "Fundamental and second-harmonic ultrasound field computation of inhomogeneous nonlinear medium with a generalized angular spectrum method", *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, vol. 58, no. 7, pp. 1366-1376, 2011.
- F. Varray, C. Cachard, P. Tortoli, and O. Basset, "Nonlinear Radio Frequency Image Simulation for Harmonic Imaging - CREANUIS", *IEEE International Ultrasonics Symposium*, San Diego, USA, pp. 2179-2182 , 2010.

8 Bibliography

[1] F. Varray, A. Ramalli, C. Cachard, P. Tortoli, and O. Basset, "Fundamental and second-harmonic ultrasound field computation of inhomogeneous nonlinear medium with a generalized angular spectrum method", *IEEE Trans Ultrason Ferroelectr Freq Control,* vol. In press, 2011.

[4] http://www.cecill.info/licences/Licence_CeCILL-B_V1-en.html

[2] F. Varray, C. Cachard, P. Tortoli, and O. Basset, "Nonlinear radio frequency image simulation for harmonic imaging - CREANUIS", in *IEEE Ultrasonics Symposium*, San Diego, 2010.

[3] F. Varray, C. Cachard, P. Tortoli, and O. Basset, "Simulation of (3D+t) nonlinear pressure field propagation on GPU with the Angular Spectrum Method", in *IEEE Ultrasonics Symposium*, Orlando, 2011.

[4] M. Frigo and S. G. Johnson, "The Design and Implementation of FFTW3", *Proceedings of the IEEE,* vol. 93, n. 2, pp. 216-231, 2005.

[5] T. L. Szabo, "Generalized Fourier transform diffraction theory for parabolically anisotropic media", *The Journal of the Acoustical Society of America,* vol. 63, n. 1, pp. 28-34, 1978.